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First Named Inventor	Mark S. Zediker
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APPLICATION FOR REISSUE OF:
(check applicable box)



Utility Patent



Design Patent



Plant Patent

APPLICATION ELEMENTS

- ☒ * Fee Transmittal Form (PTO/SB/56)
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- ☒ Specification and Claims (amended, if appropriate)
- ☒ Drawing(s) (proposed amendments, if appropriate)
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(PTO/SB/53 or PTO/SB/54)
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- Original U.S. Patent currently assigned?
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☐ Written Consent of all Assignees (PTO/SB/53 or 54)
☐ 37 C.F.R. § 3.73(b) Statement ☐ Power of Attorney

ACCOMPANYING APPLICATION PARTS

- ☐ Foreign Priority Claim (35 U.S.C. 119)
(if applicable)
- ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
- ☐ English Translation of Reissue Oath/Declaration
(if applicable)
- * Small Entity Statement(s) ☐ Statement filed in prior application, Status still proper and desired
(PTO/SB/09-12)
- ☐ Preliminary Amendment
- ☒ Return Receipt Postcard (MPEP 503)
(Should be specifically itemized)
- ☒ Other: Request to Transfer Drawings

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diffraction pattern 26 is produced in accordance with typical binary optic technology, as well known to those of ordinary skill in the art (See U.S. Pat. No. 4,846,552.), further discussion of this technology will not be provided.

5 The binary optic diffraction pattern 26 is typically an eight phase level structure (although a two, four, or sixteen-phase level structure could also be utilized) which corrects for optical path differences inherent in the divergent output light of an emitter of a semiconductor laser array. Thus, the rays
10 of light which exit the binary optic element 24 will have all travelled equal optical pathlengths, defined as a physical pathlength multiplied by the index of refraction of the material through which the light rays travelled which are equal or varied from that equal optical pathlength by only an integer multiple of the wavelength of the light being emitted.
15 An eight level binary optic diffractive pattern 26 is shown schematically in FIG. 1.

A two-dimensional semiconductor laser array can be fabricated from a plurality of the one-dimensional semiconductor laser arrays 10 shown in FIG. 1. The one-dimensional
20 semiconductor laser arrays 10 are stacked as shown in FIG. 2 within a heatsink which serves as a holding or clamping fixture 70. The clamping fixture 70 is designed such that the one-dimensional semiconductor laser arrays 10 may be
25 stacked on top of one another so that the outputs of each one-dimensional semiconductor laser array are substantially parallel to the outputs of the other semiconductor laser arrays.

Once the one-dimensional semiconductor laser arrays 10
30 have been mounted within the clamping fixture 70, the collimating lenses are aligned and attached. The fabrication of the collimating lenses is done in a manner identical to that previously discussed such that the refractive lens 22 is cemented to the binary optical element 24 which has been
35 designed to collimate the laser output of each emitter 20. The alignment and attachment of the collimating lenses is accomplished in a sequential fashion for optimum efficiency. The collimating lenses 80a associated with the first one-dimensional semiconductor laser array 10a are positioned as
40 previously described such that the optical axes of each emitter 20 of the semiconductor laser array 10 are substantially aligned with the center of the collimating lens assembly 80a.

The second collimating lens assembly 80b is then placed
45 in front of a second one-dimensional semiconductor laser array 10b and is held in position by means of a vacuum chuck 76 connected by a vacuum line to a vacuum source, as shown in FIG. 3. The two-dimensional semiconductor laser array 10 is then supplied power such that the emitters
50 20 produce a light output. A transform lens 72 is positioned within the path of the light emitted from the first and second one-dimensional semiconductor laser arrays. The transform lens 72 may be a plano-convex or a biconvex lens, as shown in FIG. 3, such that a simulated far field will appear at the
55 focal plane of the transform lens 72 when the input light to the transform lens 72 is collimated. To determine the simulated far field, when all beams of light overlap at the focal plane of the transform lens 72, a line scan detector 74 is positioned at the focal plane. The output of the line scan
60 detector is monitored to determine if proper collimation has been achieved. The position of the second collimating lens assembly 80b is varied until proper collimation is observed at the focal plane of the transform lens. Once proper collimation is observed, the position of the second collimating lens assembly 80b is preserved by fixing the lens
65 assembly in position in the ears 25 of the clamping fixture 70. An identical alignment procedure is done for each lens

assembly and its corresponding one-dimensional semiconductor laser array 10, until the lens assembly for each semiconductor laser array 10 has been properly aligned such that the light is collimated and focused at the simulated far field.

The two-dimensional laser array when properly supplied with power produces a single collimated spot of laser output in the far field. By utilizing a plurality of one-dimensional semiconductor laser arrays 10 whose outputs may be combined, the output power of the two-dimensional semiconductor laser array may be quite high. For example, 25 watts of continuous wave laser energy was produced by a two-dimensional semiconductor laser array consisting of twelve one-dimensional semiconductor laser arrays with each one-dimensional semiconductor laser array having twenty one emitters. Additionally, the overall efficiency of the laser array from electrical input to power in the central lobe was approximately 26%.

U.S. Pat. No. 5,299,222 discloses an alternative approach to producing a high power laser diode system that collects and concentrates laser output from a stack of diode laser bars in a form that is useful and flexible for pumping a laser, e.g., a solid state laser. As shown schematically in FIG. 4, the light beam output of stacked diode laser bars is coupled into a plurality of optical fibers. The output light beams from the fibers may be used to pump a laser resonator. The fibers can be grouped at various end points of a solid-state laser cavity for efficient end-pumping. In FIG. 4, a light beam 11 is emitted by a plurality of diode laser bars in a diode laser bar stack 13, and light from a selected group of the bars is collected by one of a plurality of cylindrical lenses 15 positioned adjacent to but spaced apart from each diode bar in the stack 13. Each diode laser bar may have an aspect ratio (length-to-width) as high as 10,000:1, or even higher, and the cylindrical lenses 15 are interposed to reduce the beam divergence angle in a first direction, relative to the beam divergence angle in a second, perpendicular direction, so that the resulting beam divergence angle in each of the two directions is roughly the same.

Two or more turning mirrors 17A, 17B, 17C and 17D separate mutually exclusive portions of the light beam 11 into non-overlapping light beam components 19A, 19B, 19C and 19D, respectively, and at least one pump light beam component, such as 19E, is optionally defined by a portion of the light beam 11 that does not encounter a turning mirror. Each light beam component 19A, 19B, 19C, 19D and 19E is then focussed by suitable focusing optics 21A, 21B, 21C, 21D and 21E, respectively, into a corresponding multimode optical fiber 23A, 23B, 23C, 23D and 23E, respectively, with the diameters of the fibers being chosen to fully capture the optical beam intended for that fiber. Preferably, the sine of the convergence angle as a light beam arrives at a light-receiving end of a fiber is less than the numerical aperture NA of that fiber. In one embodiment, each optical fiber has a diameter of about 500 μm , but this fiber diameter may be as large as a few mm. Each of the focusing optics 21j (j=A, B, C, D or E) may be a lens with a short focal length, such as $f=6.35$ mm, and is intended to cause the resulting beam to converge to an entrance diameter, measured at the entrance of the corresponding fiber 23j, that is about 25 percent of the diameter of the portion of the pump light beam 11 that arrives at the focusing optics 21j.

The numerical aperture NA of the multimode fiber 23j lies in the range 0.15–0.3 but may be as high as 0.6. Each optical fiber 23j delivers the component pump light beam propagating therein to a selected position and with a selected angular orientation relative to the laser cavity to be pumped

by this collection of component pump light beams. Each optical fiber 23j is provided with an anti-reflective coating at the diode laser wavelength P, and the coating is either applied directly to the fiber end or to a separate glass window that is bonded to the light-receiving end of that fiber. The core material of the fiber 23j may be glass, and the cladding material of the fiber may be glass or plastic, with a smaller refractive index than the core refractive index, which determines by the numerical aperture of the fiber in a manner well known in the art.

It will be appreciated that expansion of the systems discussed immediately above would require both a large amount of real estate and complex optic assemblies to couple the outputs of a plurality of the disclosed output modules to a single spot. For example, the presence of lens 72 in FIG. 3 suggests the need for a focusing lens associated with each module; FIG. 4 suggests that a plurality of lenses 21 are needed to efficiently couple the output of a single diode laser array. It would be desirable for a plurality of semiconductor laser arrays to produce a single spot of high intensity laser output using a simple and robust optical subsystem. Furthermore, it would be desirable for a plurality of semiconductor laser arrays to be mounted evenly and the outputs thereof collimated in such a manner as to fill the available aperture to thereby provide a substantially constant intensity across the single spot of laser output produced.

SUMMARY OF THE INVENTION

Based on the above and foregoing, it can be appreciated that there presently exists a need in the art for a diode laser system which overcomes the above-described deficiencies.

An object according to the present invention is to provide a direct diode laser system generating a high fluence level at a workpiece.

Another object according to the present invention is to provide a direct diode laser system which generates a high power laser beam. According to one aspect of the present invention, the high power laser beam can be focused onto a single spot for interaction with a workpiece. According to another aspect of the present invention, the high power laser beam may be directed into one end of a solid state laser.

A still further object of the present invention is to provide a direct diode laser system which generates a high fluence level at a workpiece using dichroic coupling of multiple frequency collimated laser beams. Advantageously, all of the collimated laser beams can be generated using laser diode arrays.

Yet another object of the present invention is to provide a direct diode laser system which generates a high fluence level at a workpiece using both dichroic and polarization coupling of multiple frequency collimated laser beams. Advantageously, all of the collimated laser beams can be generated using laser diode arrays.

An additional object of the present invention is to provide a direct diode laser system which generates a high fluence level at a workpiece by simultaneously coupling thousands of collimated laser diode outputs into a single fiber via a single lens.

Another object of the present invention is to provide a direct diode laser system which generates a linearly scalable high power level output.

These and other objects, features and advantages of the present invention are provided by a direct diode laser system which includes N laser head assemblies (LHAs) generating N output beams, N optical fibers receiving respective ones

of the N output beams and generating N received output beams, and a torch head recollimating and focusing the N received output beams onto a single spot. According to one aspect of the invention, each of the laser head assemblies of the direct diode laser system includes M modules generating M laser beams, wherein each of the M laser beams has a corresponding single wavelength of light, M-1 dichroic filters, wherein each of the M-1 dichroic filter transmits a corresponding one wavelength of the M laser beams and reflects all other wavelengths of the M laser beams, and a fiber coupling device collecting the M laser beams to produce a respective one of the N output beams.

These and other objects, features and advantages of the present invention are provided by a direct diode laser system, including N laser head assemblies (LHAs) generating N output beams, wherein each of the N laser head assemblies includes M first modules generating M first laser beams, wherein each of the M first laser beams has a corresponding single wavelength of light, M-1 first dichroic filters defining a first optical waveguide for directing all of the M first laser beams into a first optical path, wherein each of the M-1 first dichroic filters transmits a corresponding one of the M first laser beams having a respective wavelength and reflects all other wavelengths of the M first laser beams, a fiber coupling device disposed adjacent to the first optical path for collecting the M first laser beams to produce a respective one of the N output beams, N optical fibers receiving respective N output beams and generating N received output beams, and a torch head recollimating and focusing the N received output beams on a single spot.

These and other objects, features and advantages according to the present invention are provided by a method for generating a high energy laser beam, including steps for:

- (a) generating P collimated laser beams having an Mth wavelength;
- (b) repeating step (a) M times so as to produce M×P collimated laser beams having M different wavelengths;
- (c) coupling the M×P collimated laser beams into an optical path;
- (d) coupling the M×P collimated laser beams into an ith optical fiber to thereby produce a corresponding ith output laser beam, where i=1 to N;
- (e) repeating steps (a) through (d) N times to thereby generate N output laser beams;
- (f) recollimating the N output laser beams to produce N recollimated laser beams; and
- (g) focusing the N recollimated laser beams onto a single spot.

These and other objects, features and advantages of the invention are disclosed in or will be apparent from the following description of preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

These and various other features and aspects of the present invention will be readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a perspective view of a one-dimensional semiconductor laser array assembly, a refractive lens, and a binary optic element;

FIG. 2 is a two-dimensional semiconductor laser array and its associated collimating optics held within a clamping fixture;

FIG. 3 is a side view of a transform lens in a two-dimensional semiconductor laser array structure illustrating the proper collimation of laser diode outputs by a collimating lens assembly;

FIG. 5 is a high level block diagram of a high efficiency, high power direct diode laser system according to the present invention;

FIG. 7 is a detailed schematic diagram of the optic bed of one of the assemblies illustrated in FIG. 6, which is useful in understanding one facet of system power scaling according to the present invention;

FIG. 9 is an illustration of an exemplary configuration of the torch head assembly of FIG. 5.

FIG. 5 is a high level block diagram of the high efficiency, high power direct diode laser system (DLS) 1 according to alternate preferred embodiments of the present invention. As illustrated in FIG. 5, the DLS 1 includes a power supply 100 providing power to both a controller 200 and N laser head assembly (LHA) controllers generally denoted 300. N laser head assemblies (LHAs) generally denoted 400 receive the output power of the LHA controllers 300, respectively, and provide N optical output laser beams to a torch head 500 via N optical fibers. It should be mentioned that the torch head 500 advantageously can be augmented by a laser head 510 (See FIG. 9.), and, thus, the alternative designation in FIG. 5.

In an exemplary embodiment of the DLS 1 of FIG. 5, the power supply provides DC power to controller 200 and LHA controllers 300. Preferably, controller 200 acts as a master controller with respect to the N LHA controllers 300, which act as slave controllers. It should also be mentioned that each of the N LHA controllers 300 controls and varies the output optical beam of the respective LHA 400, as discussed in greater detail below.

FIG. 6 is an intermediate level block diagram showing 65 additional details of the LHA 400 and torch head 500 components illustrated in FIG. 5. Advantageously, each of the N LHAs 400 includes M diode laser modules 410, of

As discussed immediately above and as shown in FIG. 7, twelve 100 watt collimated diode laser modules 410, six each in left and right groups, are combined for launching into a single optical fiber. It should be noted that each module 410 in one of the left and right groups of modules 410 produces laser light at a single selected wavelength. Preferably, the selected wavelength corresponds to the band-pass wavelength of one of the dichroic filters 420. The selected wavelength preferably is within the range of approximately 450 nm to 2.5 microns, and the selected wavelengths preferably all fall within the 760-1050 nm range, with the range of 800-980 nm being most preferable for the exemplary case illustrated in FIG. 7. It should also be mentioned that the minimum differential wavelength for any two of the modules 410 is approximately 10 nm, which corresponds to the minimum band pass of the dichroic filters 420 available using present technology. Thus, the number M of modules 410 in each LHA 400 is 20 for each 100 nm in bandwidth of the output of torch head 500 when both dichroic filters 420 and polarizer 450 are employed and 10 for each 100 nm in bandwidth when only dichroic filters 420 are employed. However, the number M of modules can be

increased as the passband of each of the dichroic filters 420 decreases. It should be mentioned that dichroic filters 420 advantageously can be low, high or band pass filters.

It will also be appreciated that the wavelengths produced by the modules 410 advantageously can be selected to facilitate use of the DLS 1. For example, a single one of the modules 410 can produce a wavelength in the visible portion of the spectrum so as to provide a guide beam for reasons of safety.

Each of the modules 410 advantageously can be constructed as shown in FIG. 8, wherein a plurality of laser diode arrays 414 are supported by a heatsink 412 within a case 418. Preferably, 3 or more tilt correcting mirrors 416 are used to combine the outputs of the laser diode arrays 414 into a highly collimated output beam. Preferably, each module 410 advantageously includes P laser diodes. It will be appreciated that the only significant limit on the number P is the number of laser diodes which can be effectively cooled.

It should be noted that the modules 410, while similar to those disclosed in U.S. Pat. No. 5,212,707 in some respects, are significantly different in a number of other respects. The modules described in U.S. Pat. No. 5,212,707 were actually fabricated and tested as part of a 100 watt fiber coupled system that was sold by the assignee in 1993. While these modules produced highly collimated laser diode arrays, there have since been several new developments in technology that have enabled the modules 410 to be enhanced vis-a-vis those disclosed in U.S. Pat. No. 5,212,707. For example, the basic emitters used in the patent were index guided devices, i.e., rib lasers. In contrast, the modules 410 according to the present invention advantageously can be gain guided structures, in particular, 20 micron wide oxide defined stripes. While the laser diode array 414 does not produce the same divergence as the index guided structures described in U.S. Pat. No. 5,212,707, they do produce significantly higher output power levels. Moreover, the additional improvements that have developed since the '707 patent was issued include:

- (a) The use of high power index guided devices, such those found in Model No. SDL 5410 by Spectra Diode Labs, Inc.;
- (b) The use of a tapered oscillator design which is, in general, an oxide defined stripe but with a diverging wavefront; and
- (c) Improved binary optics, whereby it is no longer necessary to use a refractive element to share the power and collimate the light from the emitters. It will be appreciated that this latter improvement alone increases the effective fluence produced by each of the laser diode arrays 414.

Implementing all of these improvements collectively can dramatically increase the brightness of the module 410 over the original design used in the modules described in U.S. Pat. No. 5,212,707.

It should also be noted that the module 410 illustrated in FIG. 8 includes pointing mirrors 416 in the basic module structure. These pointing mirrors are used to direct the output beam exiting the module 410 through the optical path illustrated in FIG. 7 and into the optical fiber 470. Advantageously, the pointing mirrors 416 provide the fine adjustments required to achieve a high coupling efficiency to the optical fiber 470. It should also be noted that the first commercial systems according to U.S. Pat. No. 5,212,707 provided 100 watt output power by polarization coupling two of the laser diode arrays shown in FIGS. 2 and 3. This approach to intramodule coupling was discarded in favor of

Another improvement to the basic design of the modules 410 is the use of stackable microchannel coolers to increase the packing density of the laser diodes and consequently reduce the overall size of the system. Advantageously, cooling systems such as that disclosed in U.S. Pat. No. 5,495,490, which patent is incorporated by reference for all purposes, can be used.

As discussed above, the DLS 1 shown in FIG. 5 is for an exemplary case in which the output beams of four LHAs 400 are combined to deliver over 3200 watts of cw power to a single focusing lens 506. It should be noted that the output beam of each LHA 400 is produced by dichroic and polarization combining of the outputs of twelve modules 410.

As discussed above, the output of each respective module is fiber coupled to an optical fiber 470. It should be noted that the transform lens 464 focuses and couples the entire output beam of LHA 400 into fiber 470. Preferably, the sine of the convergence angle as the light beam arrives at the light-receiving end of the fiber 470 is less than the numerical aperture NA of that fiber. Advantageously, the NA of the fiber 470 is less than 0.47. Preferably, the NA of the fiber 470 is ≤ 0.19 and, most preferably, the NA of the optical power is ≤ 0.16 .

Preferably, the fiber coupling lens 464 is a lens designed specifically for focusing the collection of beams from the

wide wavelength band system of LHA 400 into the optical fiber 470. The number of modules 410 shown in the exemplary case illustrated in FIG. 7 was chosen to meet the optical power budget required at the fiber output and is entirely dependent on the quality of the optics used. As discussed previously, the only criteria is that the system produce 800 watts out of the fiber and be contained within a 0.16 NA.

Those of ordinary skill in the art will appreciate that the commercial applications range from surgery, to cutting, welding, and heat treating metals. In addition, this DLS 1 will be ideal for paint stripping, curing, cutting and drilling composite materials. Military applications range from an off-gimbal illumination system to a delay denial system for nuclear storage areas.

Another key application for this technology will be as an optical pump for solid state lasers, as discussed above, based on rare earth elements. This configuration facilitates excellent end pumping of a solid state laser rod, rare-earth doped fiber or dye laser. Moreover, this configuration has proven to be the most efficient means yet devised for converting incoherent laser diode pump light into a high quality, high brightness beam.

Although a presently preferred embodiment of the present invention has been described in detail hereinabove, it should be clearly understood that many variations and/or modifications of the basic inventive concepts herein taught, which may appear to those skilled in the pertinent art, will still fall within the spirit and scope of the present invention, as defined in the appended claims.

What is claimed is:

1. A diode laser system, comprising:

N laser head assemblies (LHAs) generating N output beams, wherein each of said N LHAs includes:

M modules generating M laser beams, wherein each of said M laser beams has a different single wavelength; M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams;

a fiber coupling device collecting said M laser beams to produce a respective one of said N output beams;

N optical fibers receiving respective ones of said N output beams and generating N received output beams; and

an optical assembly recollimating and focusing said N received output beams on a single spot,

where N and M are both integers ≥ 2 .

2. The diode laser system as set forth in claim 1, further comprising N LHA controllers controlling the output power produced by respective ones of said N LHAs.

3. The diode laser system as set forth in claim 1, further comprising a LHA controller controlling the output power produced by all of said N LHAs.

4. The diode laser system, as set forth in claim 1, wherein said optical assembly comprises:

N collimating lenses for recollimating respective ones of said N output beams; and

a single transform lens focusing said recollimated N output beams onto said single spot.

5. The diode laser system as set forth in claim 4, wherein said single spot corresponds to one end of a solid state laser rod.

6. The diode laser system as set forth in claim 4, wherein said single spot corresponds to one end of a rare earth doped optical fiber.

7. The diode laser system as set forth in claim 1, wherein each of said LHAs comprises:

5 a polarizer disposed at the intersection of said first and second optical paths coupling said M first and M second laser beams into the second optical path to thereby produce 2M polarization coupled laser beams; wherein said fiber coupling device collects said 2M polarization coupled laser beams to produce a respective one of said N output beams.

15 **14. A diode laser system, comprising:**
means for generating N laser beams, wherein each of said
N laser beams includes multiple wavelengths of light
and wherein said generating means comprises:

25 M-1 first filter means defining a first optical waveguide for directing all of said M first laser beams into a first optical path, wherein each of said M-1 first filter means transmits a corresponding one of said M first laser beams and reflects all other said M first laser beams;

N optical fiber means receiving respective one of said N output laser beams for generating N received output beams; and

where N and M are both integers ≥ 2 .

40 N collimating lenses for recollimating said N×M laser beams; and

16. The diode laser system as set forth in claim 14,
45 wherein said single spot corresponds to one end of a solid
state laser.

18. The diode laser system as set forth in claim 14,
wherein said single spot corresponds to one end of a dye
laser.

55 second means for generating M second laser beams, wherein each of said M second laser beams has a different single wavelength;

rotating means for rotating the polarizations of said M
65 second laser beams; and

polarization means disposed at the intersection of said first and second optical paths for coupling said M first

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and M second laser beams into said second optical path to thereby produce 2M polarization coupled laser beams.

wherein said fiber coupling means collects said 2M polarization coupled laser beams to produce a respective one of said N laser beams. 5

20. The diode laser system as set forth in claim 19, wherein said fiber coupling device comprises a transform lens for receiving and for coupling said 2M polarization coupled laser beams to one of said N optical fiber means to thereby produce a respective one of said N output beams. 10

21. A method for generating a high energy laser beam, comprising:

- (a) generating P collimated laser beams having an Mth wavelength; 15
- (b) repeating step (a) M times so as to produce M×P collimated laser beams having M different wavelengths;
- (c) coupling said M×P collimated laser beams into an optical path;

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(d) coupling said $M \times P$ collimated laser beams into an i th optical fiber to thereby produce a corresponding i th output laser beam, where $i=1$ to N ;

5 (e) repeating steps (a) through (d) N times to thereby generate N output laser beams;

(f) recollimating said N output laser beams to produce N recollimated laser beams; and

(g) focusing said N recollimated laser beams onto a single spot.

10 where M , N and P are integers ≥ 2 .

22. The method as set forth in claim 21, wherein step (c) comprises dichroically coupling said $M \times P$ collimated laser beams into said optical path.

23. The method as set forth in claim 21, wherein step (c) 15 comprises dichroically and polarization coupling said $M \times P$ collimated laser beams into said optical path.

24. The method as set forth in claim 21, wherein step (c) comprises polarization coupling said $M \times P$ collimated laser beams into said optical path.

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25. A diode laser system, comprising:

a laser head assembly generating an output beam, the laser head assembly including:

M modules which generate M laser beams, wherein each of said M laser beams has a different single wavelength; and

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams into a predetermined optical path to produce said output beam,

where M is an integer ≥ 2 .

26. A diode laser system, comprising:

a laser head assembly which generates an output beam, the laser head assembly including:

M modules which generate M laser beams, wherein each of said M laser beams occupies a different wavelength band;

M-R dichroic filters, wherein each of said M-R dichroic filters transmits at least a respective one of said M laser beams occupying a given wavelength band and reflects all other of said M laser beams not occupying the given wavelength band; and
an optical device which combines said M laser beams to thereby produce said output beam,

wherein:

M and R are positive integers; and

M is an integer ≥ 2 .

27. The diode laser system as recited in claim 26, wherein the optical device comprises means for collecting said M laser beams to thereby produce said output beam.

28. The diode laser system as recited in claim 26, wherein the optical device comprises a fiber coupling device which collects said M laser beams to thereby produce said output beam.

29. The diode laser system as recited in claim 26, wherein the optical device comprises a polarization combiner which combines first selected ones of said M laser beams with second selected ones of said M laser beams to thereby produce said output beam.

30. The diode laser system as recited in claim 29, wherein the first selected ones of said M laser beams are equal in number to the second selected ones of said M laser beams.

31. A laser head assembly which generates an output beam including M laser beams, comprising:

M modules generating M laser beams, wherein each of said M laser beams has a different single wavelength; and

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams;

wherein M is an integer ≥ 2 .

1 32. The laser head assembly as recited in claim 31, further comprising a fiber coupling device
2 collecting said M laser beams to produce an output beam;

1 33. A method for generating a high energy laser beam, comprising:
2 (a) generating P collimated laser beams having an Mth wavelength;
3 (b) repeating step (a) M times so as to produce MxP collimated laser beams having M
4 different wavelengths; and
5 (c) coupling said MxP collimated laser beams into an optical path to produce a high energy
6 laser beam,
7 wherein M and P are integers ≥ 2 .

1 34. The method as recited in claim 33, wherein the step (c) comprises dichroically coupling
2 said MxP collimated laser beams into said optical path.

1 35. The method as recited in claim 33, wherein the step (c) comprises dichroically and
2 polarization coupling said MxP collimated laser beams into said optical path.

1 36. A diode laser system, comprising:
2 laser head assembly (LHA) which generates an output beam, the LHA including:
3 M modules generating M laser beams, wherein each of said M laser beams has a different
4 single wavelength;
5 M-1 dichroic filters defining an optical waveguide for directing all of said M laser beams into
6 the optical path, wherein each of said M-1 first dichroic filters transmits a corresponding one of said
7 M laser beams and reflects all other said M laser beams; and
8 a fiber coupling device disposed adjacent to the optical path for collecting said M laser beams
9 to thereby produce an output beam;
10 where M is an integer ≥ 2 .

1 37. A diode laser system, comprising:
2 laser head assembly (LHA) which generates an output beam, the LHA including:
3 M first modules generating M first laser beams, wherein each of said M first laser beams has
4 a different single wavelength;
5 M-1 first dichroic filters defining a first optical waveguide for directing all of said M first
6 laser beams into a first optical path, wherein each of said M-1 first dichroic filters transmits a
7 corresponding one of said M first laser beams and reflects all other said M first laser beams;
8 M second modules generating M second laser beams, wherein each of said M second laser
9 beams has a different single wavelength;
10 M-1 second dichroic filters defining a second optical waveguide for directing all of said M
11 second laser beams into a second optical path, wherein each of said M-1 second dichroic filters
12 transmits a corresponding one of said M second laser beams and reflects all other said M second
13 laser beams;
14 a polarization combiner disposed at the intersection of said first and second optical paths

which coupling said M first and M second laser beams into the second optical path to thereby produce 2M polarization coupled laser beams; and
a fiber coupling device disposed adjacent to said first and second optical paths for coupling said 2M polarization coupled laser beams to thereby produce the output beam,
where M is an integer ≥ 2 .

38. A laser head assembly (LHA) which generates an output beam, comprising:
M modules generating M laser beams, wherein each of said M laser beams has a different single wavelength;

M-R dichroic filters defining a first optical waveguide for directing all of said M laser beams into a first optical path, wherein each of said M-R dichroic filters transmits at least one of said M laser beams;

S second modules generating S laser beams, wherein each of said S laser beams has a different single wavelength;

S-T dichroic filters defining a second optical waveguide for directing all of said S laser beams into a second optical path, wherein each of said S-T dichroic filters transmits at least one of said S laser beams;

a polarization combiner disposed at the intersection of said first and second optical paths which couple said M and said S laser beams into a common optical path to thereby produce M + S polarization coupled laser beams; and

a fiber coupling device disposed adjacent to said first and second optical paths for coupling said M + S polarization coupled laser beams to thereby produce the output beam,

wherein:

M, R, S and T are positive integers; and

at least one of M and S is ≥ 2 .

39. A diode laser system, comprising:
means for generating M laser beams, each of said M laser beams having a different wavelength;

M-R filter means defining a first optical waveguide for directing all of said M first laser beams into an optical path, wherein each of said M-R filter means transmits at least one of said M first laser beams; and

fiber coupling means disposed adjacent to said optical path for collecting said M laser beams to thereby produce an output laser beam,

wherein M and R are both positive integers, and

wherein $M \geq 2$.

40. A diode laser system, comprising:
first means for generating M first laser beams, wherein each of said M first laser beams has a different single wavelength;

M-1 first filter means defining a first optical waveguide for directing all of said M first laser beams into an optical path, wherein each of said M-1 filter means transmits a corresponding one of said M first laser beams and reflects all other said M first laser beams;

second means for generating M second laser beams, wherein each of said M second laser beams has a different single wavelength;

M-1 second filter means defining a second optical waveguide for directing all of said M second laser beams into a second optical path, wherein each of said M-1 second filter means transmits a corresponding one of said M second laser beams and reflects all other said M second laser beams;

polarization combining means disposed at the intersection of said first and second optical paths for coupling said M first and said M second laser beams into said second optical path to thereby produce 2M polarization coupled laser beams; and

fiber coupling means disposed adjacent to said second optical path for collecting said 2M polarization coupled laser beams to thereby produce an output laser beam,

wherein M is a integer ≥ 2 .

41. A method for generating a high energy laser beam, comprising:

(a) generating P collimated laser beams having an Mth wavelength;

(b) repeating step (a) M times so as to produce M×P collimated laser beams having M different wavelengths;

(c) coupling said M×P collimated laser beams into an optical path; and

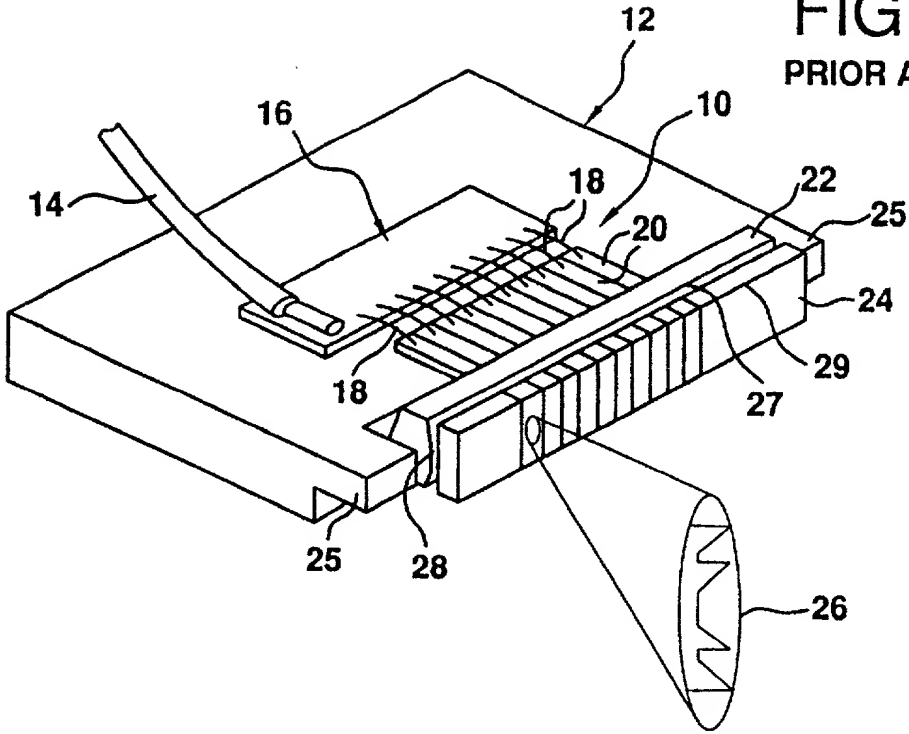
(d) coupling said M×P collimated laser beams into an ith optical fiber to thereby produce a corresponding ith output laser beam, where $i=1$ to N;

where M, N and P are positive integers and both M and $P \geq 2$.

ABSTRACT

A direct diode laser system includes N laser head assemblies (LHAs) generating N output beams. N optical fibers receiving respective N output beams and generating N received output beams, and a torch head recollimating and focusing the N received output beams onto a single spot. Preferably, each of the laser head assemblies of the direct diode laser system includes M modules generating M laser beams, wherein each of the M laser beams has a corresponding single wavelength of light. $M-1$ dichroic filters, wherein each of the $M-1$ dichroic filter transmits a corresponding one of the M laser beams and reflects all other wavelengths, and a fiber coupling device collecting the M laser beams to produce a respective one of the N output beams. In an exemplary case, the $M-1$ dichroic filters function as band pass filters. A method of generating a high fluence, high power laser beam is also described.

PRIOR ART



PRIOR ART

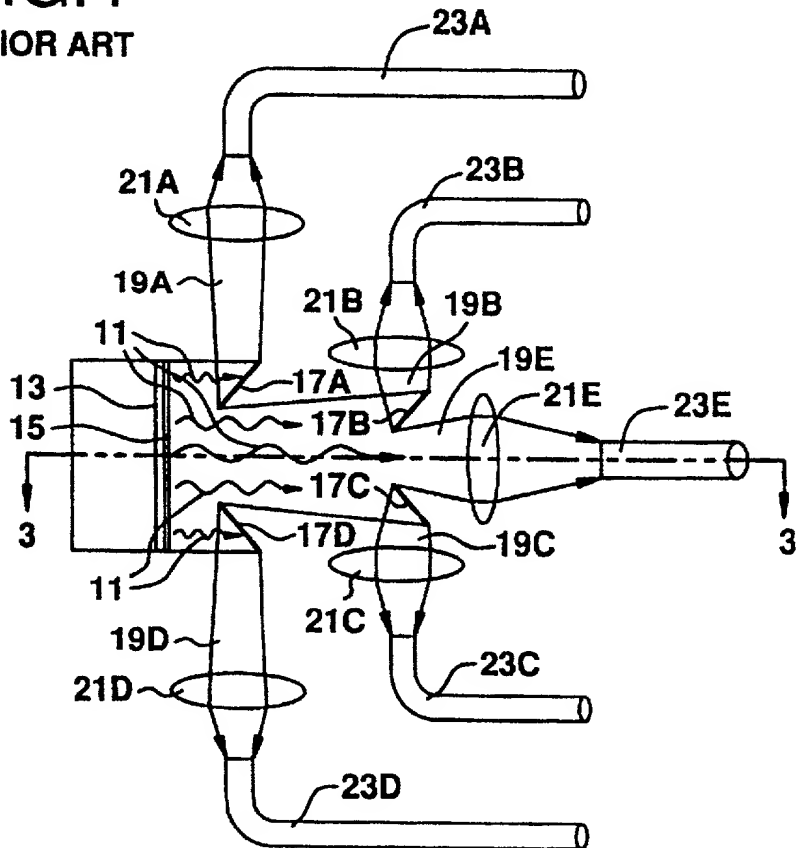


FIG.2
PRIOR ART

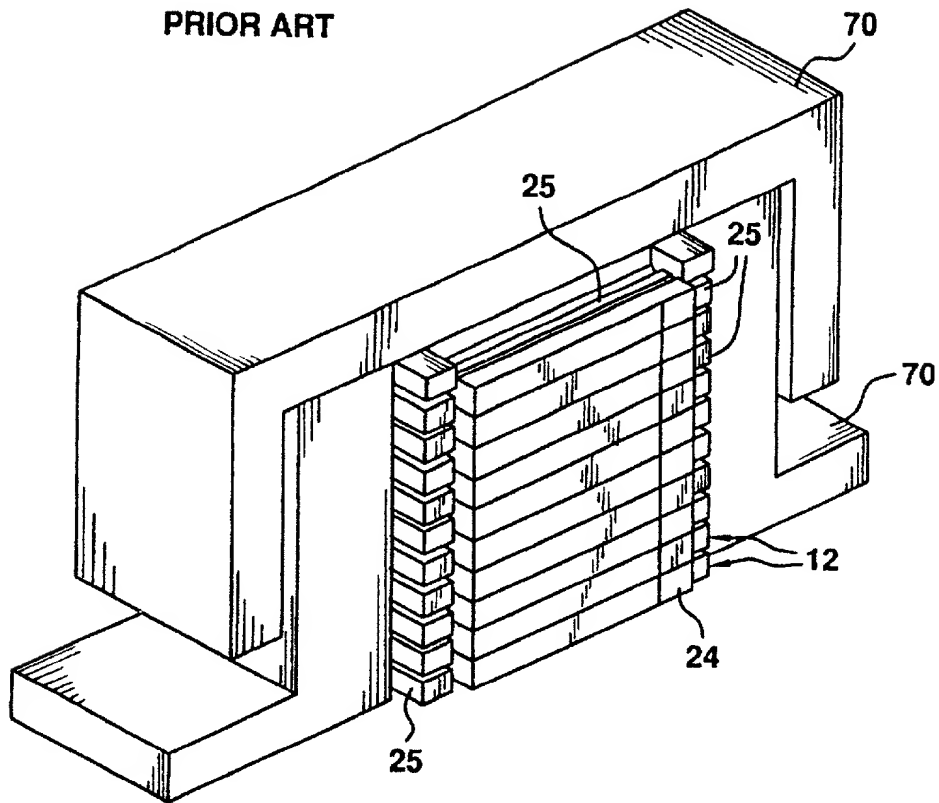


FIG.3
PRIOR ART

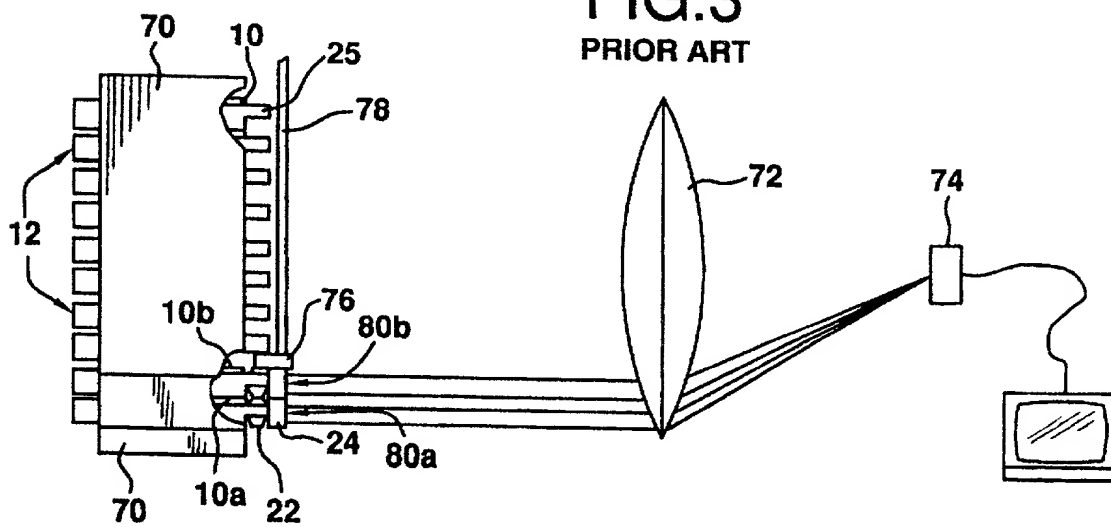


FIG.6

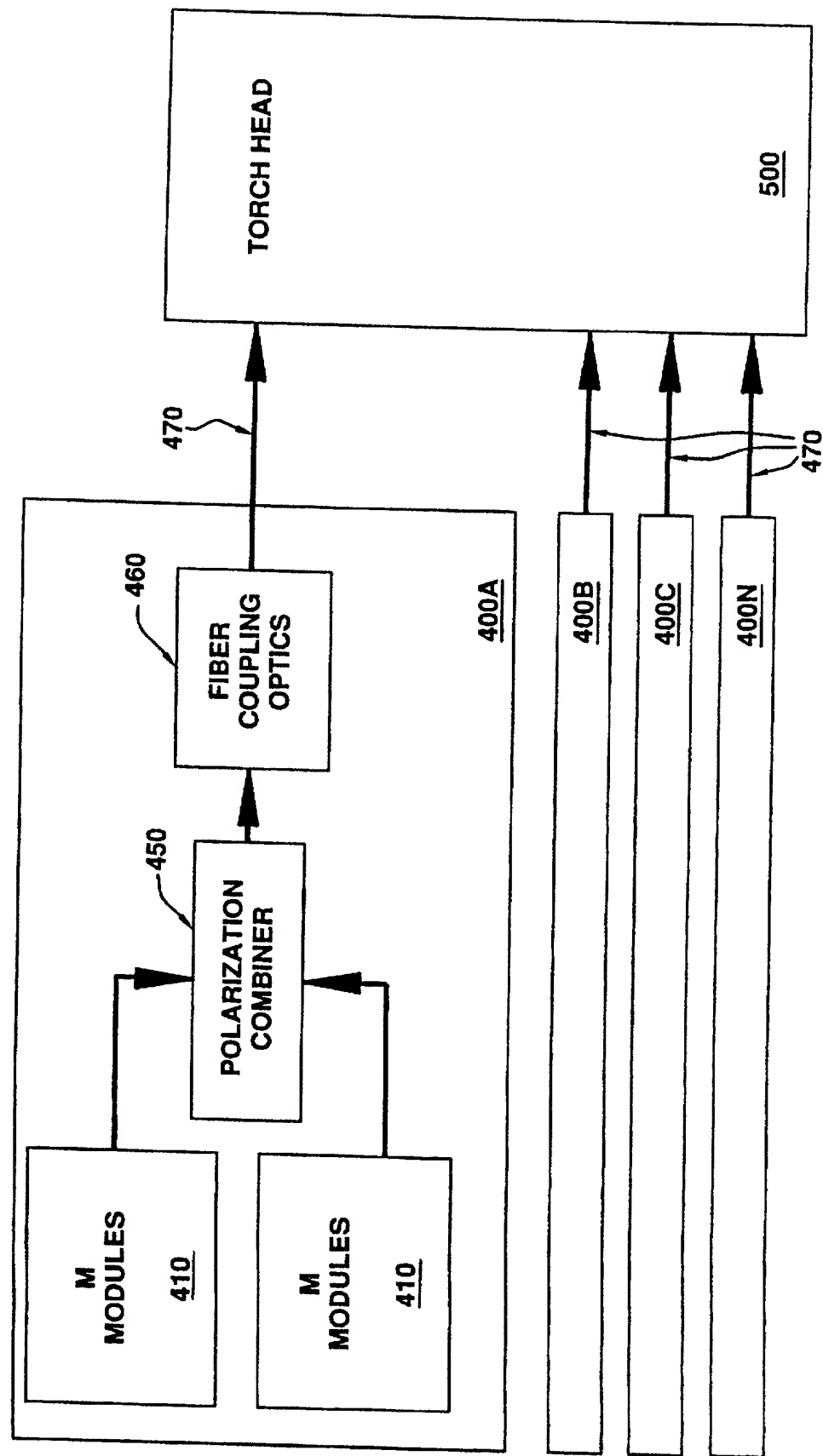


FIG.8

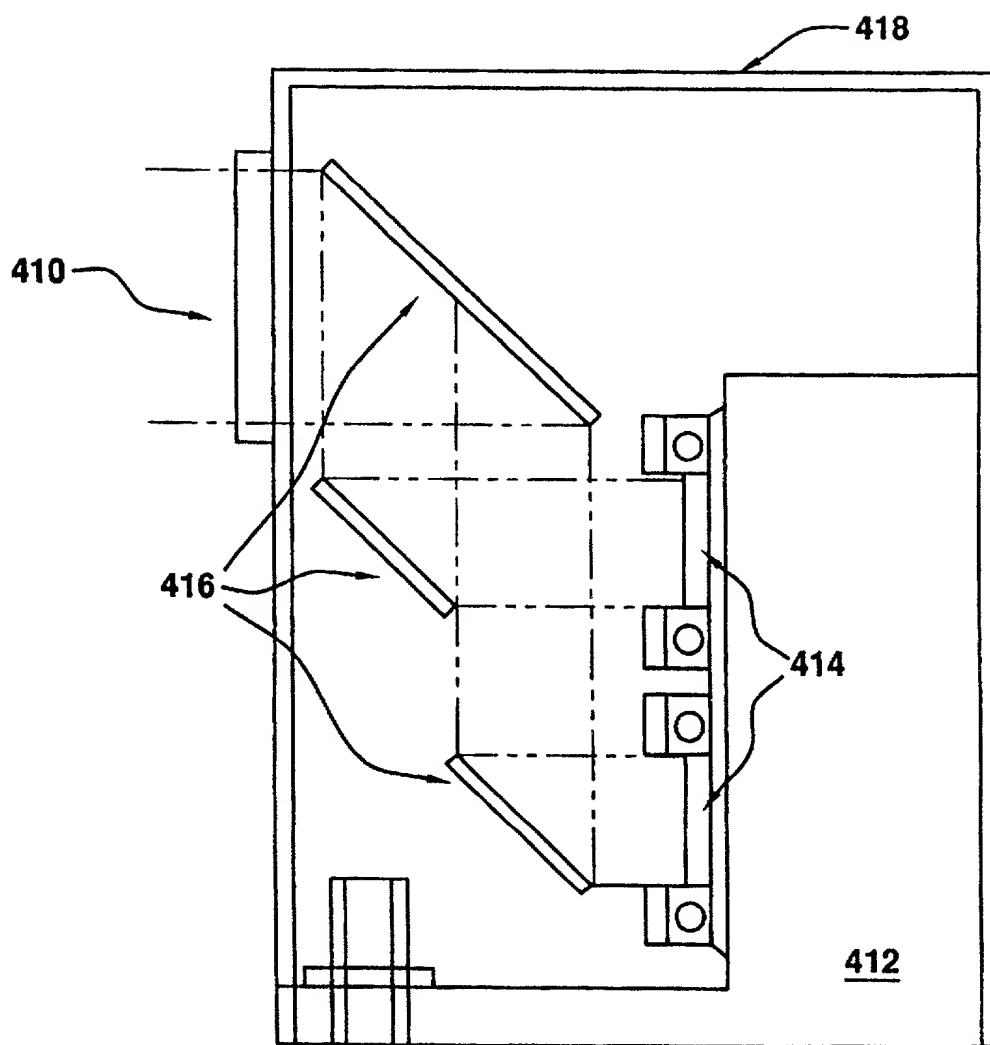
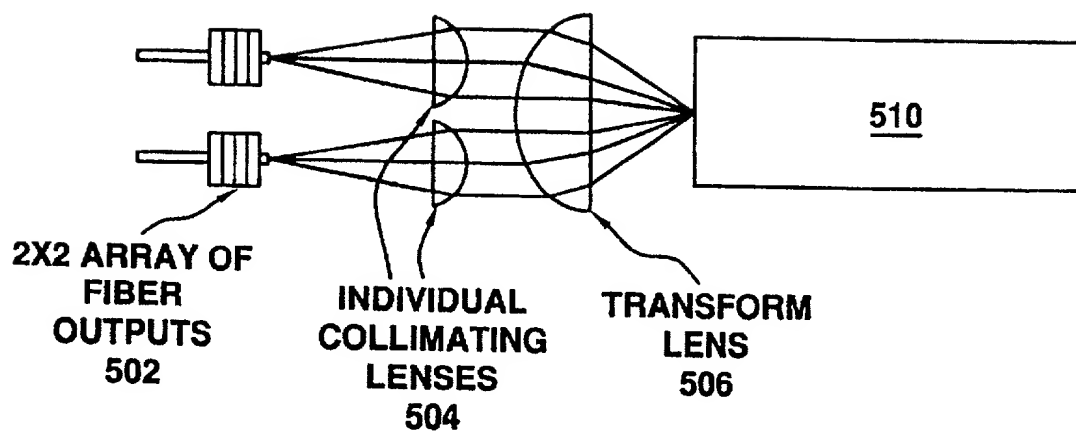


FIG.9



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REISSUE APPLICATION DECLARATION BY THE INVENTOR

Docket Number (Optional)

D-3953-RE

DEC 29 2000

As a below named inventor, I hereby declare that:

My residence, mailing address and citizenship are stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is described and claimed in patent number 5,715,270, granted 02/03/1998, and for which a

reissue patent is sought on the invention entitled HIGH EFFICIENCY, HIGH POWER DIRECT DIODE LASER SYSTEMS AND METHODS THEREFOR, the specification of which

☐ is attached hereto.

☒ was filed on 02/03/2000 as reissue application number 09/498,254
and was amended on N/A.
(If applicable)

I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I verily believe the original patent to be wholly or partly inoperative or invalid, for the reasons described below. (Check all boxes that apply.)

☐ by reason of a defective specification or drawing.

☒ by reason of the patentee claiming more or less than he had the right to claim in the patent.

☐ by reason of other errors.

At least one error upon which reissue is based is described below. If the reissue is a broadening reissue, such must be stated with an explanation as to the nature of the broadening:

In U.S. Patent No. 5,715,270, Applicants erroneously, and without deceptive intent, claimed less than they were entitled to claim. For example, claim 1 of the '270 patent recited:

1. A diode laser system, comprising:

N laser head assemblies (LHAs) generating N output beams, wherein each of said N LHAs includes:

M moduls generating M laser beams, wherein each of said M laser beams has a different single wavelength;

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams;

[Page 1 of 2]

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D-3953-RE

It will be appreciated from a comparison of claims 1 of the '270 patent and claim 25 of the Reissue application, the recitation of but a single laser head assembly permits additional elements, such as the N optical fibers of claim 1 to be omitted from the claimed diode laser system.

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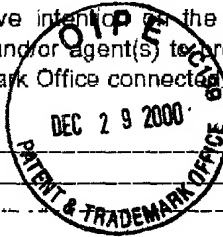
(REISSUE APPLICATION DECLARATION BY THE INVENTOR, page 2)

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D-3953-RE

All errors corrected in this reissue application arose without any deceptive intent on the part of the applicant. As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the United States Patent and Trademark Office connected therewith.

Name(s)	Registration Number
Raymond H. J. Powell, Jr.	34,231
Robert A. Westerlund	31,439
Ramon R. Hoch	34,108



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<input checked="" type="checkbox"/> Firm or Individual Name	WESTERLUND POWELL, P.C.		
Address	122 N. Alfred Street		
Address			
City	Alexandria	State	VA
Zip	22314-3011		
Country	United States		
Telephone	(703) 706-5862	Fax	(703) 706-5860
I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.			
Full name of sole or first inventor (given name, family name)			
Mark S. Zediker			
Inventor's signature	Date		
Residence	Same as Mailing Address	Citizenship	United States
Mailing Address	4005 Waneway Court, Florissant, MO 63034-3218		
Full name of second joint inventor (given name, family name)			
Robert R. Rice			
Inventor's signature	Date 18 December 2000		
Residence	Same as Mailing Address	Citizenship	United States
Mailing Address	14736 Greenleaf Valley Drive, Chesterfield MO, 63017		
Full name of third joint inventor (given name, family name)			
John M. Haake			
Inventor's signature	Date		
Residence	Same as Mailing Address	Citizenship	United States
Mailing Address	5 Gum Tree Place, St. Charles, MO, 63301-1296		
<input type="checkbox"/> Additional joint inventors are named on separately numbered sheets attached hereto.			

[Page 2 of 2]

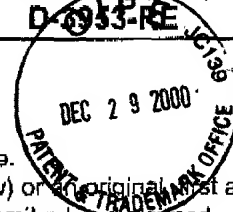
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D-4933-RE



As a below named inventor, I hereby declare that:

My residence, mailing address and citizenship are stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or the original first and joint inventor (if plural names are listed below) of the subject matter which is described and claimed

in patent number 5,715,270 granted 02/03/1998, and for which a

reissue patent is sought on the invention entitled **HIGH EFFICIENCY, HIGH POWER DIRECT DIODE**

LASER SYSTEMS AND METHODS THEREFOR

the specification of which

☐ is attached hereto.

☒ was filed on 02/03/2000 as reissue application number 09/498,254

and was amended on N/A
(If applicable)

I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I verily believe the original patent to be wholly or partly inoperative or invalid, for the reasons described below. (Check all boxes that apply.)

☐ by reason of a defective specification or drawing.

☒ by reason of the patentee claiming more or less than he had the right to claim in the patent.

☐ by reason of other errors.

At least one error upon which reissue is based is described below. If the reissue is a broadening reissue, such must be stated with an explanation as to the nature of the broadening:

In U.S. Patent No. 5,715,270, Applicants erroneously, and without deceptive intent, claimed less than they were entitled to claim. For example, claim 1 of the '270 patent recited:

1. A diode laser system, comprising:

N laser head assemblies (LHAs) generating N output beams, wherein each of said N LHAs includes:

M modules generating M laser beams, wherein each of said M laser beams has a different single wavelength;

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams;

[Page 1 of 2]

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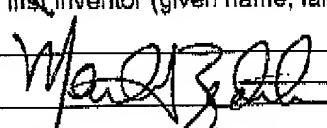
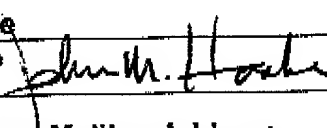
Name(s)	Registration Number
<u>Raymond H. J. Powell, Jr.</u>	<u>34,231</u>
<u>Robert A. Westerlund</u>	<u>31,439</u>
<u>Ramon R. Hoch</u>	<u>34,108</u>

Correspondence Address: Direct all communications about the application to:

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<input checked="" type="checkbox"/> Firm or Individual Name	WESTERLUND POWELL, P.C.			
Address	122 N. Alfred Street			
Address				
City	Alexandria	State	VA	Zip 22314-3011
Country	United States			
Telephone	(703) 706-5862	Fax	(703) 706-5860	
I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.				
Full name of sole or first inventor (given name, family name) Mark S. Zediker				
Inventor's signature			Date	12/20/00
Residence	Same as Mailing Address		Citizenship	United States
Mailing Address	315 Merlin Drive, St. Charles, MO 63304			
Full name of second joint inventor (given name, family name) Robert R. Rice				
Inventor's signature			Date	
Residence	Same as Mailing Address		Citizenship	United States
Mailing Address	14736 Greenleaf Valley Drive, Chesterfield MO, 63017			
Full name of third joint inventor (given name, family name) John M. Haake				
Inventor's signature			Date	12/20/00
Residence	Same as Mailing Address		Citizenship	United States
Mailing Address	5 Gum Tree Place, St. Charles, MO, 63301-1296			
<input type="checkbox"/> Additional joint inventors are named on separately numbered sheets attached hereto.				

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REISSUE APPLICATION DECLARATION BY THE INVENTOR	Docket Number (Optional) D-3953-RE
<p>a fiber coupling device collecting said M laser beams to produce a respective one of said N output beams;</p> <p>N optical fibers receiving respective ones of said N output beams and generating N received output beams; and</p> <p>an optical assembly recollimating and focusing said N received output beams on a single spot,</p> <p>where N and M are both integers ≥ 2.</p> <p>In doing so, Applicants erroneously claimed a diode laser system including at least two laser head assemblies. However, the laser diode system to which the Applicants believe they are entitled is as recited below:</p> <p>25. A diode laser system, comprising:</p> <p>a laser head assembly generating an output beam, wherein the laser head assembly includes:</p> <p>M modules which generates M laser beams, and wherein each of said M laser beams has a different wavelength band; and</p> <p>M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams into a predetermined optical path to produce said output beam; and</p> <p>where M is an integer ≥ 2.</p> <p>It will be appreciated from a comparison of claims 1 of the '270 patent and claim 25 of the Reissue application, the recitation of but a single laser head assembly permits additional elements, such as the N optical fibers of claim 1 to be omitted from the claimed diode laser system.</p>	

[Page 1A of 2]

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D-3953-R

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REISSUE APPLICATION DECLARATION BY THE ASSIGNEE

Docket Number (optional)

D-3953-RE

In U.S. Patent No. 5,715,270, Applicants erroneously, and without deceptive intent, claimed less than they were entitled to claim. For example, claim 1 of the '270 patent recited:

1. A diode laser system, comprising:

N laser head assemblies (LHAs) generating N output beams, wherein each of said

M modules generating M laser beams, wherein each of said M laser beams has a different single wavelength;

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams;

a fiber coupling device collecting said M laser beams to produce a respective one of said N output beams;

N optical fibers receiving respective ones of said N output beams and generating N received output beams; and

an optical assembly recollimating and focusing said N received output beams on a single spot.

where N and M are both integers ≥ 2 .

In doing so, Applicants erroneously claimed a diode laser system including at least two laser head assemblies. However, the laser diode system to which the Applicants believe they are entitled is as recited below:

25. A diode laser system, comprising:

a laser head assembly generating an output beam, wherein the laser head assembly includes:

M modules which generates M laser beams, and wherein each of said M laser beams has a different wavelength band; and

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams into a predetermined optical path to produce said output beam; and

where M is an integer ≥ 2 .

It will be appreciated from a comparison of claims 1 of the '270 patent and claim 25 of the Reissue application, the recitation of but a single laser head assembly permits additional elements, such as the N optical fibers of claim 1 to be omitted from the claimed diode laser system.

[Page 2 of 2]

Variable	Mean	SD	Min	Max
Age	34.5	10.2	22	55
Gender	0.5	0.5	0	1
Marital status	0.6	0.5	0	1
Education	12.5	1.5	10	15
Income	1500	500	1000	2500
Health status	0.8	0.2	0	1
Smoking status	0.3	0.5	0	1
Alcohol consumption	0.2	0.4	0	1
Exercise frequency	0.5	0.5	0	1
Stress level	0.7	0.3	0	1
Life satisfaction	0.6	0.4	0	1
Work satisfaction	0.5	0.5	0	1
Family satisfaction	0.6	0.4	0	1
Community satisfaction	0.5	0.5	0	1
Overall well-being	0.6	0.3	0	1

List of Additional Patentees

PTO/SB/52 (US-00)

Approved for use through 12/30/2000. OMB 0651-0033

U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

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REISSUE APPLICATION DECLARATION BY THE ASSIGNEE		Docket Number (Optional) D-3953-RE
Patentee John M. Haake	Citizenship United States	
Residence/Mailing Address 5 Gum Tree Place, St. Charles, MO, 63301-1296		
Patentee	Citizenship	
Residence/Mailing Address		
Patentee	Citizenship	
Residence/Mailing Address		
Patentee	Citizenship	
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STATEMENT UNDER 37 CFR 3.73(b)

Applicant/Patent Owner: **McDonnell Douglas Corporation**
Application No./Patent No.: **5,715,270** Filed/Issue Date: **February 3, 1998**
Entitled: **High Efficiency, High Power Direct Diode Laser Systems and Methods Therefor**
McDonnell Douglas Corporation, a **P O Box 516, St. Louis MO, 63166-0516**
(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that it is:

1. ☒ the assignee of the entire right, title, and interest; or
2. ☐ an assignee of less than the entire right, title and interest.
The extent (by, percentage) of its ownership interest is _____ %
in the patent application/patent identified above by virtue of either:



A. ☒ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel **8368**, Frame **0083**, or for which a copy thereof is attached.

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B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as shown below:

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The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

12/22/2000
Date

Richard J. Wickham
Typed or printed name

Signature
Chief Counsel
Title